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THE PHYSICS AND CHEMISTRY OF THE "CHALLENGER" EXPEDITION.

Report on the Scientific Results of the Exploring Voyage of H.M.S. "Challenger," 1873-76. Physics and Chemistry, Vol. II. (Published by Order of Her Majesty's Government, 1889.)

THE second volume of the Report on the Physics and Chemistry of the *Challenger* Expedition has been published, and contains matter of very great interest.

The first paper is on the compressibility of water, by Prof. Tait. He has used Amagat's "manomètre à pistons libres."

> "The principle on which the instrument works is the same as that of the Manomètre Desgoffes—a sort of inverse of that of the well-known Bramah Press. In the British instrument, pistons of very different sectional area are subjected to the same pressure (that of one mass of liquid), and the total thrust on each is, of course, proportional to its section. In the French instrument, the pistons are subjected to *equal* total thrusts, being exposed respectively to fluid pressures which are inversely proportional to their sections. The British instrument is employed for the purpose of overcoming great resistances by means of moderate forces; the French, for that of measuring great pressures in terms of small and easily measurable pressures."

By means of the instrument from his description of which the above is an extract (p. 21), Prof. Tait has determined the compressibilities of cistern water, sea water, and solutions of common salt up to pressures of 450 atmospheres, and for a range of temperature extending from 0° to 15° C. The results may be briefly summed up as follows.

The average compressibility of fresh water at 0° C. and at low pressures is 520×10^{-7} per atmosphere. The compressibility is a minimum at 60° C. Both the compressibility and the temperature at which the minimum occurs are lowered by pressure. The average compressibility for a pressure of 456·9 atmospheres is 478×10^{-7} per atmosphere, and the temperature of minimum compressibility is about 30° C. The average compressibility of sea water is about 0·92 of that of fresh water. The point of minimum compressibility is about 56° C. at atmospheric pressure.

At 0° C. the average compressibility of water per atmosphere may be expressed by the formula $0{\cdot}00186/(36 + p)$, where p is the pressure in tons per square inch. The compressibility of solutions of NaCl, containing s parts of salt to 100 of water, is given by the formula

$$0{\cdot}00186/(36 + p + s).$$

The depth of a sea about six miles deep is reduced by 620 feet by compression. If the ocean were incompressible, the level of the surface would be 116 feet higher than it is at present, and about two million square miles of land would be submerged. Finally, the maximum density-point of water is lowered by about 3° C. by an additional pressure of 150 atmospheres, and the temperature of maximum density coincides with the freezing-point at $-2^\circ{\cdot}4$ C. under a pressure of 2·14 tons per square inch.

It will be seen from this brief recapitulation of his results that Prof. Tait has carried through a very difficult research with success, and has made substantial additions to our knowledge. It may therefore appear ungracious to criticize points which do not touch the essence of the investigation, but it is impossible to read the Report without feeling that, in some respects, it falls short of the standard of classical perfection which ought to be attained in papers published at the national expense to illustrate a great national research.

In the first place, the C.G.S. system is entirely ignored. As the compressibilities are measured *per atmosphere*, this is, so far, not of importance; but in the formulæ quoted above, which express the compressibility per atmosphere, terms occur in which the pressures are measured in tons per square inch. The units are thus mixed, and though the requisite data for conversion into atmospheres are supplied, there is no doubt that foreigners will have some difficulty in interpreting the results.

Again, though we cannot but admire the scrupulous honesty with which he tells the tale, some annoyance may justly be felt that a paper should go forth to the world in a publication intended to mark the highest level to which British science has attained, marred by the confession that the author—who deservedly holds a place in the very foremost ranks of British physicists—had never heard of Van der Waals' work on the continuity of the liquid and gaseous states till the end of the year 1888.

Van der Waals' investigation was published in Dutch in 1873. In spite of the disadvantage due to the language in which it was written, its importance was at once recognized. Clerk-Maxwell gave a long account of it in NATURE in 1874 (vol. x. p. 477). He returned to the subject in a lecture delivered before the Chemical Society on February 18, 1875, and reported in full in NATURE (vol. xi. p. 357). After indicating what he considered to be the weak points of Van der Waals' theory, he added that nevertheless "his attack on this difficult question is so able and so brave, that it cannot fail to give a notable impulse to molecular science. It has certainly directed the attention of more than one inquirer to the study of the Low-Dutch language in which it is written." Maxwell again referred to Van der Waals in his articles on "Atom" and "Capillary Action," published in the "Encyclopædia Britannica" in 1875 and 1876. So important was the theory considered, that, although it was then four years old, twelve pages were devoted to it in the first number of the "Beiblätter" to *Poggendorff's Annalen* (1877). O. E. Meyer discussed it in his "Kinetische Theorie der Gase" in the same year. It is described in modern German text-books, such as Rühlmann's "Handbuch der Mechanischen Wärmetheorie," and Winkelmann's edition of Graham-Otto's "Lehrbuch der Chemie," both published in 1885. It was translated in full into German by Dr. Roth in 1881, and an English translation by Prof. Threlfall, of the University of Sydney, is about to be published by the Physical Society of London.

In spite of all this, the author of the Report we are discussing informs us, in an addendum dated August 8, 1888, that only a few days before he had been told by a visitor to his laboratory "that one of Van der Waals' papers (he did not know which, but thought it was a recent one) contains an elaborate study of the molecular pressure in fluids"; and a few lines further down he refers to "Van der Waals' memoir 'On the Continuity of the Gaseous and Liquid States,' which I have just rapidly perused in a German translation."

In view of the fact that Prof. Tait published a book on "Heat" in 1884, these statements are so astonishing that his interview with the visitor from whom he heard of Van der Waals can only be described, in the words of Mr. Montague Tigg when he discovered that Martin Chuzzlewit was in the next box in the pawn-shop, as "one of the most tremendous meetings in Ancient or Modern History."

Other indications of a lack of acquaintance with what has been done by others are not wanting. Taking $p(v - a) =$ constant, as the equation to the isothermal of a gas, and assuming that it applies approximately to a liquid, the author concludes "that water [at 0° C.] can be compressed to somewhat less than three-fourths of its original bulk, but not further." He adds that "the whole of this speculation is of the roughest character," but makes no reference to the converging lines of evidence which indicate that liquids could be compressed to from 0·2 to 0·3 of their bulk at ordinary temperatures and pressures. The numbers which lead to this conclusion are frequently in good accord, whether they are deduced from direct observation on the specific inductive capacities or the refractive indices of the liquids themselves, or from those of their vapours, or from the molecular volumes of the elements of which they are composed. The latter, however, as calculated in the few cases he discussed from Van der Waals' theory, are larger, except in the case of hydrogen, than the corresponding numbers obtained from optical or electrical measurements. Van der Waals did not deal with water-vapour, but if we use the molecular volumes for H_2 and air obtained by means of O. Meyer's modification of his theory, and take the molecular volumes of air and O_2 as identical (an assumption which will certainly make the result too large), we obtain the following values:—

Volume of the Matter in the Unit Volume of Water under Standard Conditions.

Deduced from observations on the refractive index of liquid water (L. Lorentz)	0·2061.
Deduced from observations on the refractive index of water-vapour (L. Lorentz)	0·2068.
Deduced from the molecular volumes of H_2 and O_2 obtained from refractive index or specific inductive capacity	0·23.
Deduced from the molecular volumes of H_2 and air given by Van der Waals' theory	0·33.

Prof. Tait's value is 0·717. It is certainly unfortunate that a number so widely divergent from the results of a whole literature of optical, electrical, and thermal researches should be published in a *Challenger* Report without any reference to the discrepancy. It is still more unfortunate that in discussing the theory on which this result is based the opinion should be registered that "the quantity a [in the formula $p(v - a) =$ constant] obviously denotes the ultimate volume" (p. 48). This was published sixteen years after Van der Waals had given reasons for believing that a (or, as he calls it, b) is four times the ultimate volume, and twelve years after O. Meyer had argued that the multiplier ought to be increased to $4\sqrt{2}$. The best theories on the subject are no doubt tentative, their agreement with facts is imperfect, but it is established beyond the possibility of doubt that the constant in question need not have the meaning which is here said to be obvious.

Two papers in which the compressibilities of solutions of NaCl are discussed had appeared in *Wiedemann's Annalen* some little time before the conclusion of Prof. Tait's work. Röntgen and Schneider (*Wied. Ann.*, xxix. 165, 1886) determined the relative compressibilities of water and of a number of different salt-solutions, and Schumann (*Wied. Ann.*, xxxi. 14, May 1887) gave absolute measures. Both researches were carried on at low pressures only, but they are interesting in their relation to Prof. Tait's conclusions, inasmuch as his compressibilities at low pressures are obtained (as he fully explains) by an extrapolation, and it is therefore desirable to compare them with the values given by direct observation.

In the following table the compressibilities obtained by Schumann for solutions containing given percentages of NaCl (*i.e.* parts of salt to 100 of solution) are compared with the values deduced from Prof. Tait's formula:—

Percentage.	Compressibility per atmosphere × 10^6.	
	Schumann.	Tait.
0	50·3	52·0
5	45·5	45·1
10	39·7	39·5
15	34·8	34·6
20	30·6	30·5
25	25·8	26·8

It is to be observed that the number 50·3 is assumed by Schumann from Grassi, and that it was employed in experiments made with water, for determining the effect of pressure on the internal volume of the piezometers. If it had been replaced by Prof. Tait's value, the close agreement between the results for mean percentages would be destroyed. Schumann also obtains maxima of compressibility for low percentages of certain salts, though he seems very doubtful about the validity of these results. We have no intention of entering into a detailed discussion of his work which certainly appears to require confirmation, but there is no doubt that nobody could have made a critical comparison between his own experiments and those of Schumann so well as Prof. Tait, when he had the whole subject at his fingers' ends. It is thus a real loss to science when a man of his great ability ignores an investigation published nearly a year before the date of his own paper.

The form of the formula given by Prof. Tait for the compressibility of salt-solutions is closely analogous to that deduced from theory by Prof. J. J. Thomson in his "Applications of Dynamics to Physics and Chemistry" (p. 184). He shows that if k' is the compressibility of water, and P is the internal pressure due to the solution of a salt, the compressibility of the solution is $k'/(1 + \mathrm{P}k')$. If then we put $k' = 0{\cdot}00186/(36 + p)$, Prof. Tait's formula for a salt-solution becomes $k'/\left\{1 + k'\dfrac{s}{0{\cdot}00186}\right\}$, which, since P is proportional to very similar to J. J. Thomson's expression, and would be identical with it if $P = s\ 0{\cdot}00186$ atmospheres. In that case the internal pressure due to the salt in a solution containing 20 parts of salt to 100 of water would be about the same as the internal pressure in pure water as given by Van der Waals. If, however, we attempt to apply van 't Hoff's theory of the pressure due to dissolved substances, we find, as in the examples quoted in the "Applications" (*loc. cit.*), that the observed values of Pk' are many times greater than those given by calculation.

The second Report, by Mr. Buchan, on "Atmospheric Circulation," of which we shall give some account in a future number, is rather a treatise on meteorology than a simple discussion of the *Challenger* observations. All the data, other than those derived from the expedition (which have been previously published), are set forth, and a vast collection of meteorological facts from all parts of the world is utilized.

It would be impossible to attempt to discuss Mr. Buchan's conclusions in detail, but one may be selected as an example. Twenty-six thunderstorms occurred at sea during the voyage, and of these only four took place between 8 a.m. and 10 p.m. Nineteen occurred when the ship was near the land, and these were pretty evenly distributed throughout the twenty-four hours. Over land thunderstorms are most frequent during the day. At sea thunderstorms are nocturnal, and occur chiefly during the morning minimum of pressure.

> "Over the land the maximum of thunderstorms occurs during the hours of the day when temperature is the highest, but over the open sea during those hours when temperature is lowest. The great majority of thunderstorms over the land thus occur during the part of the day when the ascensional movement of the air from the heated surface of the ground takes place" (p. 32).

These facts furnish Mr. Buchan with an interesting suggestion as to the cause of these differences:—

> "As regards thunderstorms over the land surfaces of the globe, the disturbance of atmospheric equilibrium, resulting in ascending and descending currents, is brought about mainly by the superheating of the surface and thence of the lowermost strata of the air. But as regards the open sea, this mode of disturbing the atmospheric equilibrium cannot take place, inasmuch as the influence of solar radiation is only to raise the temperature of the surface of the sea not more than a degree. Hence it is probable that the disturbance of the equilibrium of the atmosphere, in the case of thunderstorms over the open sea, is brought about by the cooling of the higher strata of the atmosphere by terrestrial radiation" (p. 34).

There can be little doubt that Mr. Murray is right in thinking that Mr. Buchan's Report will be a standard work of reference for many years to come.

The third Report, by Commander Creak, is on the Magnetical Results of the voyage. As the author has himself described the main results of his investigations in the pages of NATURE, it is unnecessary to do more than refer to its most salient features. We have two, and only two criticisms to make. Commander Creak has employed the British unit of force, and his paper will therefore be used with less comfort and ease by most magneticians than if he had employed the C.G.S. system. Perhaps, however, as an Admiralty official he felt bound to adhere to the traditions of his office. Again, we think that he has been rather too modest in the amount of space he has claimed. Like Mr. Buchan, he has used information from many sources which are not, or at all events are not stated to be, generally accessible. These he has employed in determining the rates of secular change during the last 40 years all over the globe. It would have been interesting if means could have been devised for showing not merely the results of this investigation but the data on which they are based. Again, the map in which the direction of motion—eastward or westward—of the north pole of the needle is graphically shown for the period considered would have been more valuable if the magnitudes of the mean annual motion at different places had been added. This has, in fact, been done in a recent German work on the same subject.

But if we are inclined to wish that Commander Creak had claimed a larger share of space and given more details, in what he has done he has gone beyond any previous writer. His work is of the highest importance as introducing a novel view of the causes of secular magnetic change, and in connecting it with certain definite localities.

Mr. Buchan has furnished us with new meteorological maps. Commander Creak has prepared new magnetic maps, which enable us to institute a comparison between the magnetic state of the globe in 1880 and its condition when Sabine portrayed it for an epoch some 40 years earlier. The positions of the magnetic poles and foci of maximum intensity do not appear to have altered. The secular change is associated, not with these, but with four points, towards two of which the north pole of the needle is veering, and from two of which it is apparently being repelled. The points of increasing attraction on the north-seeking pole are to the south of Cape Horn and in the south of China; the foci of diminishing attraction are in the Gulf of Guinea and near the north magnetic pole in Canada. The existence of this last focus is more or less hypothetical, but in the case of the other three the various magnetic elements concur in indicating the same neighbourhood as the centre of change. Thus not only is the secular variation of the declination of opposite signs to the east and west of these points, but the increase of the downward attraction on the north pole of the needle is a maximum near Cape Horn and in China, and a minimum (*i.e.* a maximum decrease) in the Bight of Benin.

Again the annual change of horizontal force is very small near Cape Horn, but it is decreasing in South America, and the rate of decrease is a maximum at a point between Valparaiso and Monte Video. These are precisely the kind of results which would follow from the gradual production of a subsidiary centre of relative attraction on the north-seeking pole of the magnet near Cape Horn. The real existence of the Gulf of Guinea centre is similarly confirmed. Commander Creak cautiously abstains from theorizing on these remarkable facts, but there can be no doubt that he is right in thinking that they must lead us to look for the chief causes of secular variation within the globe rather than in solar or extra-terrestrial influences. His paper will be a point of new departure in the science of terrestrial magnetism.

It will be seen from what has been said that the three Reports which have been discussed are written with a wider scope than the mere discussion of the observations made during the voyage of the *Challenger*. Prof. Tait's paper has indeed little connection with the work of the Expedition. Mr. Buchan and Commander Creak have worked up an immense amount of matter derived from other sources.

The records of the *Challenger* have not only added facts of great importance to our stock of knowledge; but have been, as it were, nuclei round which a host of other observations have crystallized into orderly arrangement. Each one of the authors has made a step forward. Prof. Tait has extended the range of pressure over which compressibilities have been measured. Mr. Buchan has attacked the diurnal climatology of the ocean. Commander Creak has given a new turn to our ideas on the secular change of terrestrial magnetism. It is only to be regretted that the exclusive use of British systems of measurement, and the other blemishes to which we have felt compelled to refer, give a certain insular appearance and character to a work of world-wide interest.

The Report on the Rock-Specimens collected on Oceanic Islands, by Prof. A. Renard, consists of 180 pages, well illustrated by woodcuts and seven maps, and constitutes a very important part of the petrology of the *Challenger* Expedition. The account of the rocks of St. Paul's from the pen of Prof. Renard has already appeared in Vol. II. (Narrative), Appendix B, of the *Challenger* Reports, and we are glad to learn from the preface to the volume now before us that the "Report on Deep-Sea Deposits" which has been so long looked for by geologists, is to be issued next month.

Mr. Murray is to be congratulated on having secured the services of so able a mineralogist and petrographer as Prof. Renard to describe the rocks brought home by the Expedition. Most of these descriptions have already appeared in the *Bulletin of the Musée Royal d'Histoire Naturelle de Belgique;* but English geologists will be glad to see them collected together and published in their own language, and in a convenient form for reference.

Prof. Renard explains in his opening remarks the grounds for publishing this account of the rock-specimens collected on the oceanic islands by the officers of the *Challenger* Expedition:—

> "Mr. Murray had discovered that loose volcanic materials played a very large part in the formation of the deposits of the deep sea, and it was considered desirable to institute a comparison between these and the products of the same origin in volcanic islands situated in or on the borders of the great ocean basins."

It is at the same time admitted, by the editor of the volume, that Prof. Renard's lithological and mineralogical descriptions must be regarded rather as contributions to the geology of the islands visited, than as supplying full and descriptive discussions of the subject.

> "The necessities of the voyage, bad weather, or the difficulties of the exploration, prevented, in many cases, the naturalists from passing more than an hour or two on shore; they were thus unable to give any detailed account of the stratigraphical relations, and the collections of hand-specimens were sometimes limited to those rocks situated near the coast."

In the case of Tenerife, of which we have such full descriptions in the writings of Von Fritsch and Reiss, and of Sauer; in that of the Cape de Verde Islands, the rocks of which have been carefully studied by Dölter; and of Fernando Noronha, which has been surveyed and its rocks admirably described by Profs. Branner and Williams, it is obvious that the description of the specimens placed in the hands of Prof. Renard can only be regarded as supplementary to the fuller and more comprehensive accounts of the geology of the islands which we already possess. But in the case of some of the smaller islands, like Tristan da Cunha, Marion Island, and Heard Island, the notes in the present Report constitute almost the only materials which exist for judging of their geological constitution and structure. In the case of the Island of St. Thomas, in the West Indies; of Kandavu, in Fiji; of the volcano of Goonong Api, in the Banda Islands; of the volcano of Ternate, and of several islands in the Philippine Group, Prof. Renard has taken the opportunity afforded to him by the receipt of interesting specimens casually collected, to discuss points of considerable mineralogical and geological interest.

Quite apart from their connection with certain localities, these very careful notes of Prof. Renard on peculiarities exhibited by rock-forming minerals are of much value to geologists; and so also are the series of analyses of these rock-specimens, made, evidently with great care, by Dr. Klement.

So many of the islands visited by the *Challenger* were previously touched at by the *Beagle*, on board of which Charles Darwin was acting as naturalist, that it is impossible to avoid comparing the work before us with that author's classical memoir, "Geological Observations on the Volcanic Islands," which was published in 1844 and re-issued in 1876. In spite of the improvements of our petrographical methods during the half-century, which has witnessed the application of the microscope to the study of rocks, it is very interesting to see how often observations made by Darwin, aided by that great pioneer in crystallographic research, Prof. W. H. Miller of Cambridge, are confirmed by the painstaking labours of Prof. Renard. There is, perhaps, some danger, at the present day, that the facilities afforded for the microscopic study of rocks, by the aid of transparent sections, should lead geologists and mineralogists to despise, or to regard as of small value, the observations made without such aid. To those who entertain such an idea, it will be instructive to see how Darwin and Miller by the aid of pocket-lens, knife-blade, and magnet, were often able to form an appreciation of the mineralogical constitution of rocks, which has been very largely confirmed by the application of the more refined methods of the present day.

The discussion of great geological problems, which, as treated by Darwin in 1844, contributed so largely to the interest excited by his book, have of course not come within the scope of the work undertaken by Prof. Renard. The particular varieties of volcanic rocks in Ascension, which Darwin found to illustrate in so striking a manner the origin of foliation in the crystalline schists, do not seem to have been among those collected by the officers of the *Challenger*. But as an important contribution to micropetrography, the work of Prof. Renard is of the highest value, as might indeed have been anticipated from the well-proved skill and acumen of the author in this interesting branch of scientific research.